

Combined Remote-Sensing, In-Situ and Modelling of Cloud Microphysical Perturbations in Supercooled Stratus Clouds

PolarCAP

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PROM All-hands Meeting – 26.07.2024



ETH zürich



PolarCAP and CLOUDLAB

By utilizing cloud **seeding**, it is possible to disentangle the contributions of **primary** and **secondary** ice formation to the glaciation process of **supercooled** stratiform clouds from **spectral bin modelling** and **observations**.



-10...0 °C

supercooled stratus

Seeding drone (ETH)

Holo-Balloon (ETH)

COSMO-SPECS

Seeded INP

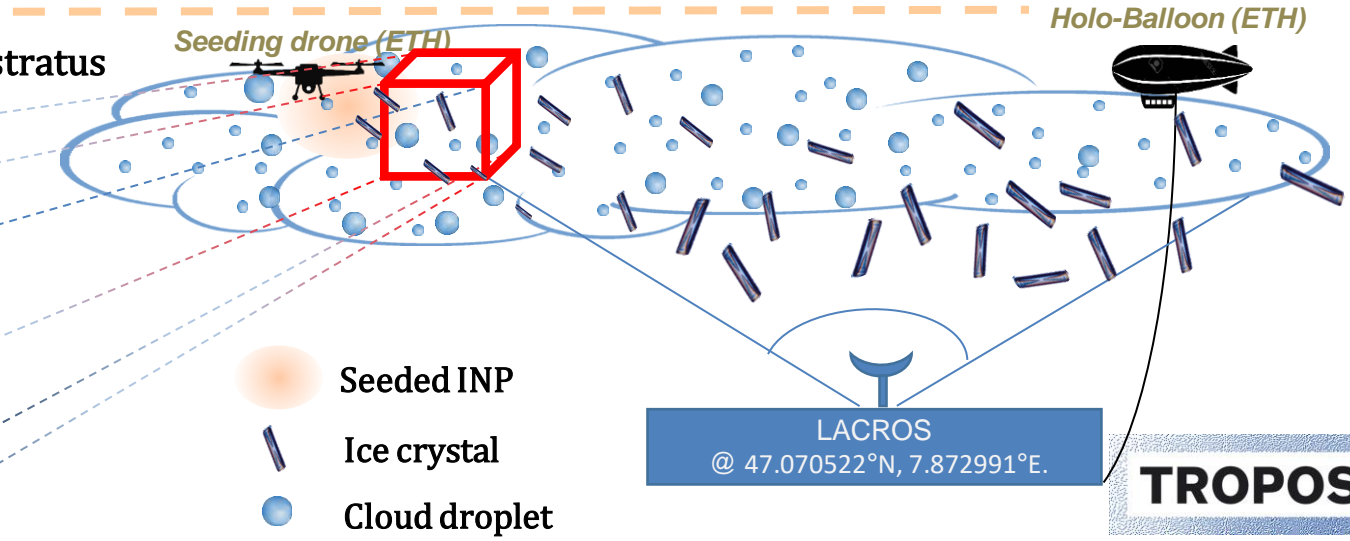
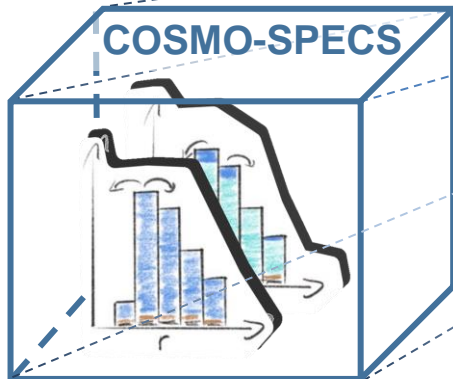
Ice crystal

Cloud droplet

LACROS

@ 47.070522°N, 7.872991°E.

TROPOS



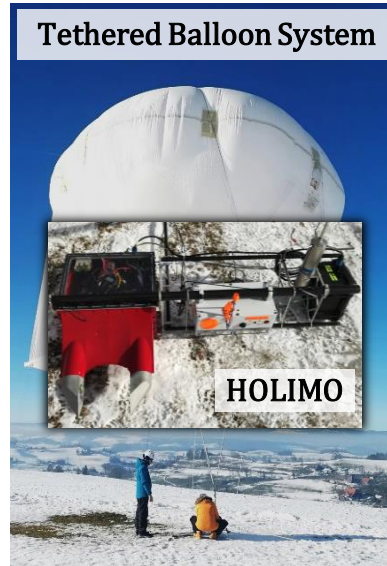
Focus Of This Presentation

Remote-Sensing:
cloud radar
MIRA35



Source: K. Ohneiser (adapted)

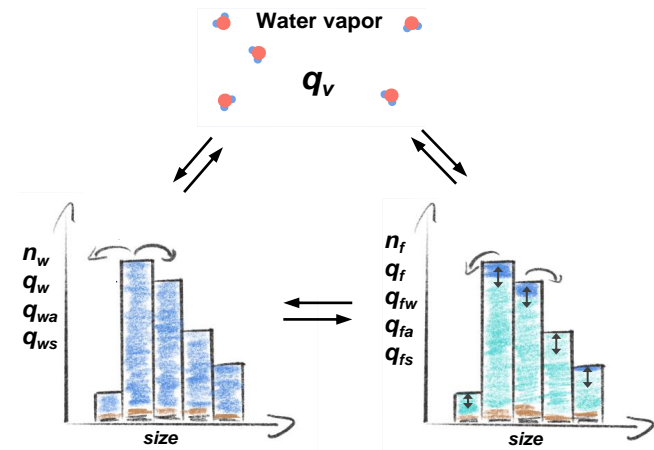
In-Situ:
holographic imager
HOLIMO



Source: C. Fuchs (adapted)

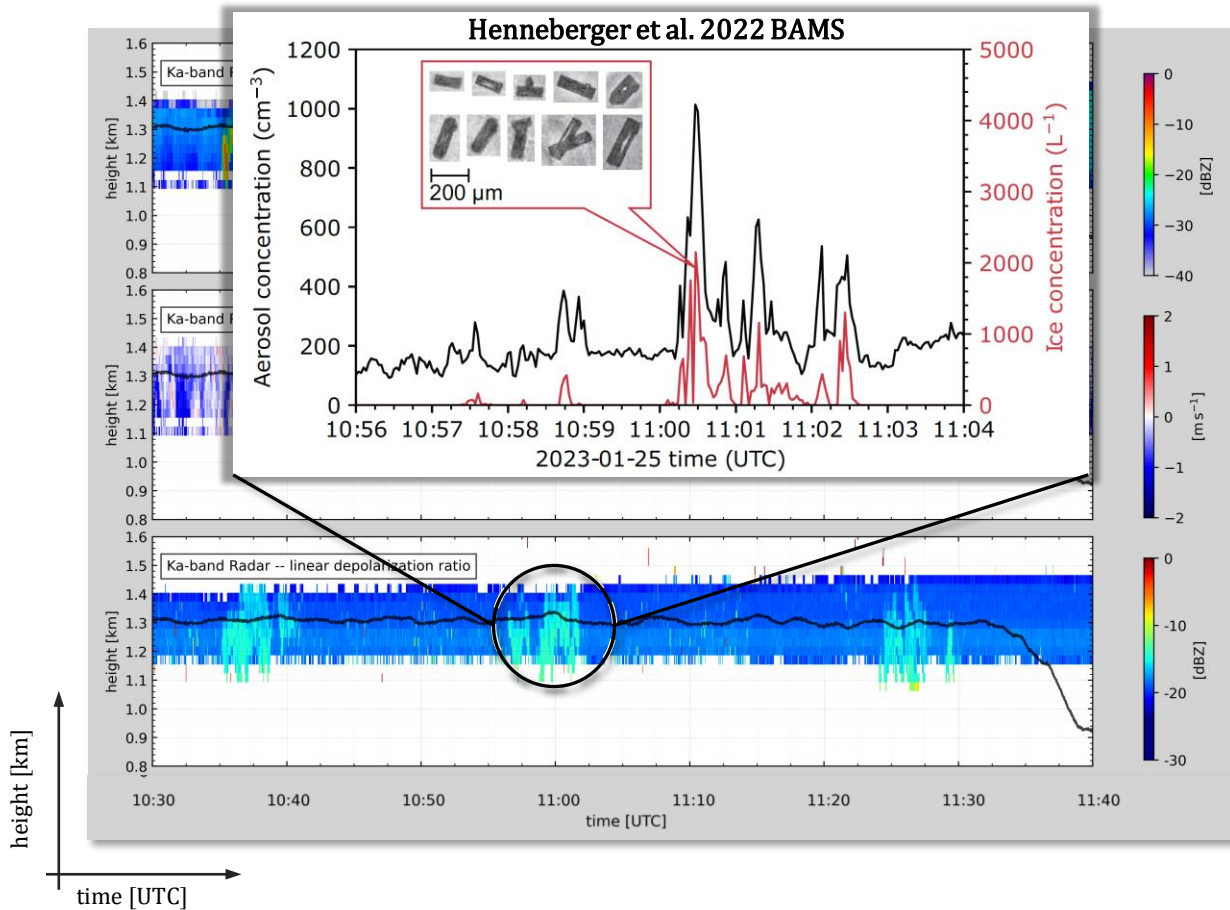
TBS ... Tethered Balloon System

Model Domain:
spectral bin microphysics
COSMO-SPECS



Source: R. Schrödner (adapted)

TROPOS



Profiles at Rapiere Platz: 25. January 2023

- Bise cloud situation
- three seeding events conducted
- reflectivity 10 – 25dBZ above background \rightarrow *ice production*
- up-/downdrafts visible in mean Doppler velocity
- LDR \sim -15dB and $Z_e >$ -20dBZ \rightarrow columnar growth
- peak ice crystal concentration $\sim 2000\text{L}^{-1}$
- HOLIMO shows (hollow) columns

COSMO-SPECS Model Domain: Eriswil



400m - Resolution

dims	N cells	resolution	size
x (lon)	50	360 m	18 000 m
y (lat)	40	400 m	16 000 m
z (hgt)	100	9 m – 520 m	900 m – 21500 m

Runtime 3 h simulation: 4.5 h on 1 node on Levante (128p)

100m - Resolution

dim	N cells	resolution	size
x (lon)	200	90 m	18 000 m
y (lat)	160	100 m	16 000 m
z (hgt)	100	9 m – 520 m	900 m – 21500 m

Runtime 3 h simulation: 12 d on Gauss5 (176p)



COSMO-SPECS-Flare Setup

COSMO-SPECS-Flare **adds** and **artificial CCN** and **INP source** to an individual grid cell.

- two switches control the **background** concentration of **CCN** and **INP**
- two switches control the **seeding**, which adds **CCN** and **INP**

Parameter

Values

Background concentration:

INP (fixed value) in $[L^{-1}]$:: N^{INP} {500}

CCN (*varies, 2 modes*) in $[cm^{-3}]$:: N_1^{CCN}, N_2^{CCN} {1035, 600, 200}, {40.5, 20.5, 2.5}

Seeding concentration:

INP (*varies*) in $[L^{-1}s^{-1}]$:: N_{flare}^{INP} {None, 10^{10} , 10^{16} }

CCN in $[cm^{-3}]$:: N_{flare}^{CCN} {None}

⇒ Number of model runs:

27

Seeding Experiment: 25. January 2023

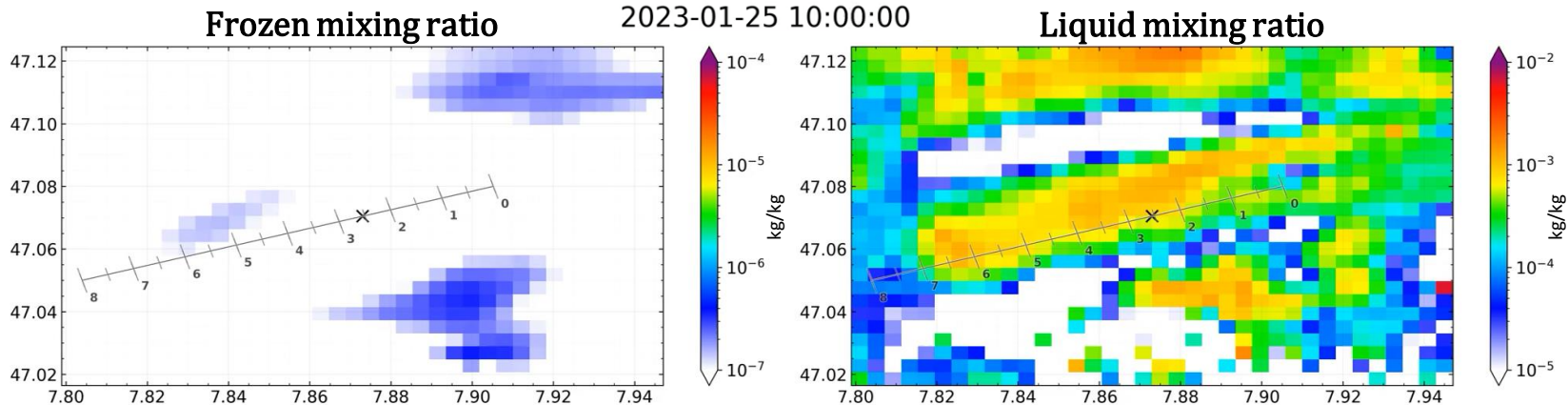
Parameter	CLOUDLAB Seeding	Model Seeding
Seeding Mission	SM58, SM59, SM60	-
Distance [m]	2000, 3000, 2500	2500
Altitude [m] MSL	1300	1350
Flight Speed [ms^{-1}]	5.2	0.0
Flare Burning Time [s]	340	160
Restart Interval [s]	-	1420



Source: Jan Henneberger

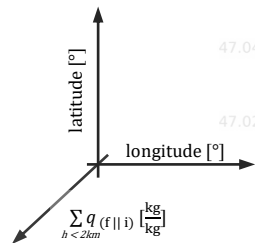
COSMO-SPECS-FLARE Results (1h spin-up)

400m
resolution



Preliminary

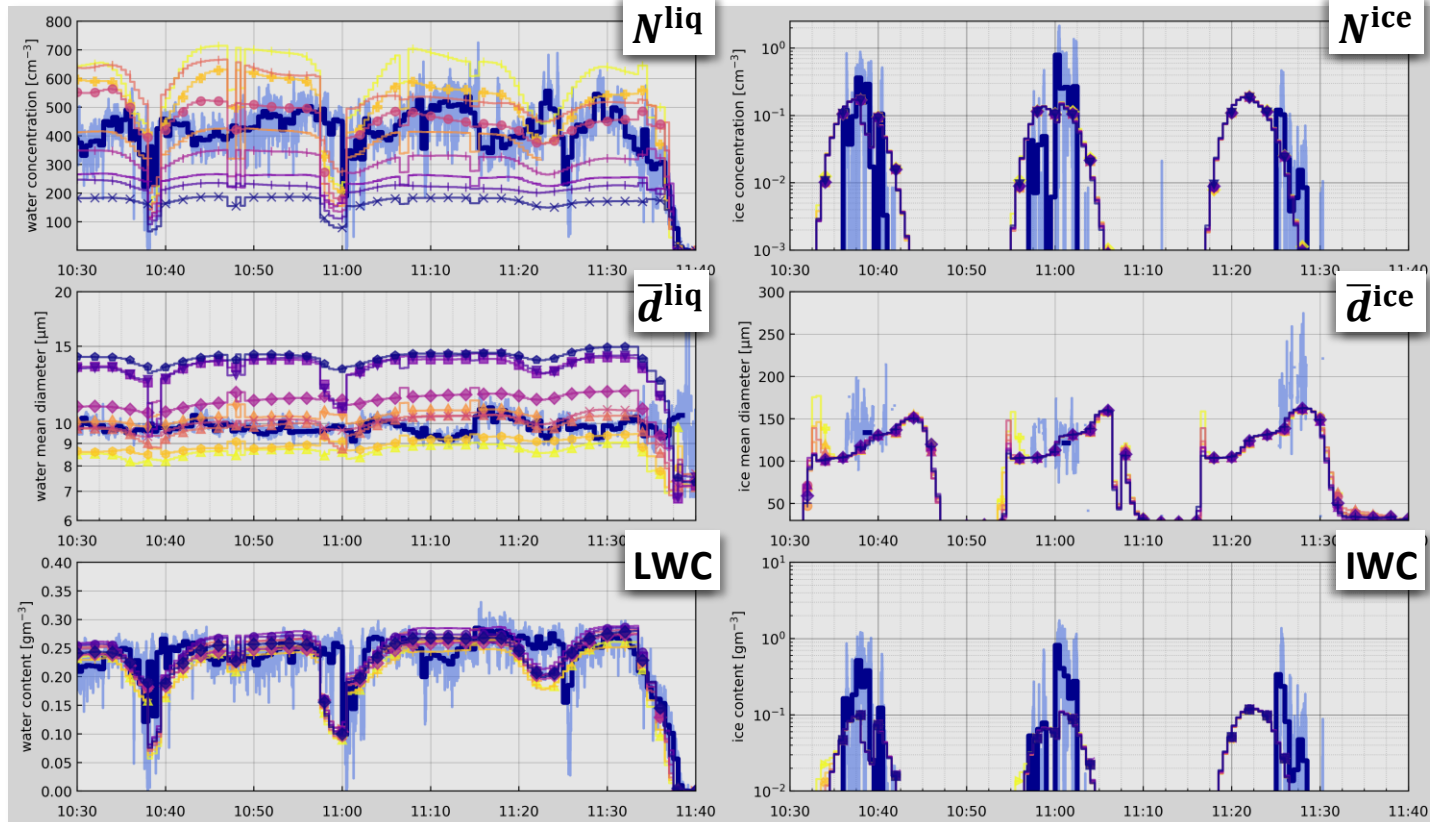
100m
resolution



X LACROS Observations

TROPOS

Bulk Time Series – Model Ensembles vs. HOLIMO



	N_1^{CCN} [cm ⁻³]	N_2^{CCN} [cm ⁻³]
M-[	1035.0,	40.5,
M-[	1035.0,	20.5,
M-[	1035.0,	2.5,
M-[	600.0,	40.5,
M-[	600.0,	20.5,
M-[	600.0,	2.5,
M-[	200.0,	40.5,
M-[	200.0,	20.5,
M-[	200.0,	2.5,
holimo 1 sec		
holimo 30 sec		

$d_1^{liq} = 100$ [nm], $\sigma_1^{liq} = 1.5$ [nm]
 $d_2^{liq} = 350$ [nm], $\sigma_2^{liq} = 2.4$ [nm]
 flare emissions = 10^{16} [L⁻¹s⁻¹]



Spectra – Model Ensembles vs. HOLIMO

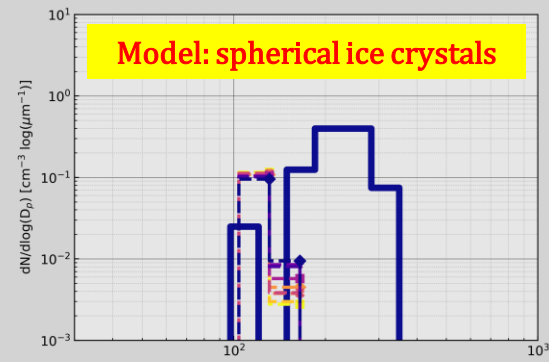
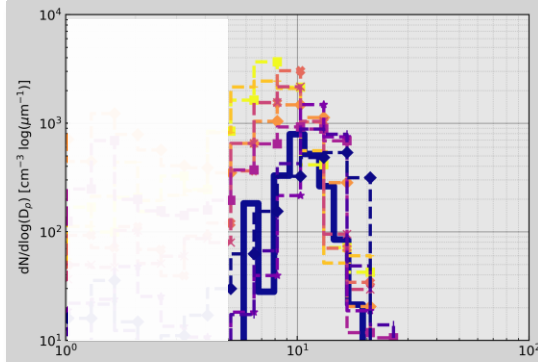
flare
[L⁻¹s⁻¹]

Liquid Distribution

Frozen Distribution

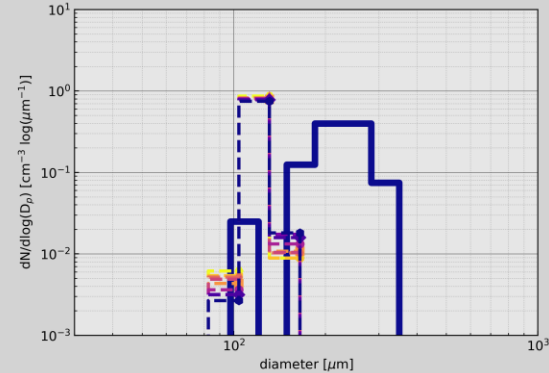
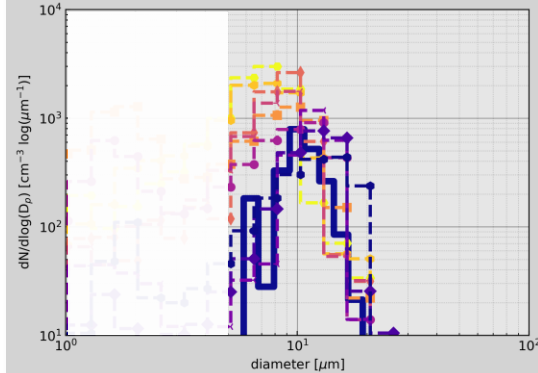
N_1^{CCN} [cm⁻³] N_2^{CCN} [cm⁻³]

10¹¹



- M-[1035. 40.5]
- M-[1035. 20.5]
- M-[1035. 2.5]
- M-[600. 40.5]
- M-[600. 20.5]
- M-[600. 2.5]
- M-[200. 40.5]
- M-[200. 20.5]
- M-[200. 2.5]
- holimo

10¹⁶



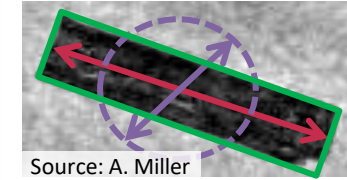
- M-[1035. 40.5]
- M-[1035. 20.5]
- M-[1035. 2.5]
- M-[600. 40.5]
- M-[600. 20.5]
- M-[600. 2.5]
- M-[200. 40.5]
- M-[200. 20.5]
- M-[200. 2.5]
- holimo

Varying background CCN:

- HOLIMO detection limit at 6μm (liquid droplets), 25μm (ice crystal)
- better fit using lower initial concentrations

Varying seeding INP:

- large amounts of flare emissions required to resemble amplitude of HOLIMO measurements
- model ice crystal diameter smaller by a factor of ~2



Size information from HOLIMO :

- Major axis length
- Minor axis length
- Equivalent size
- Area

concentration
[cm⁻³ log(μm⁻¹)]

diameter [μm]

Spectra – Model Ensembles vs. HOLIMO

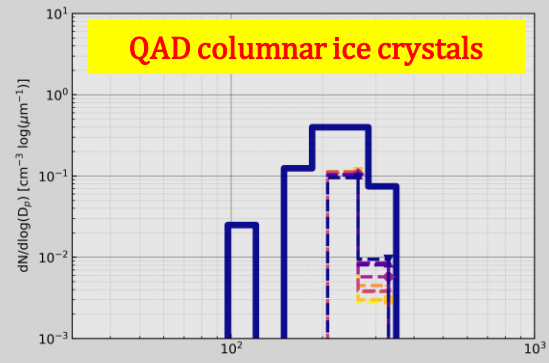
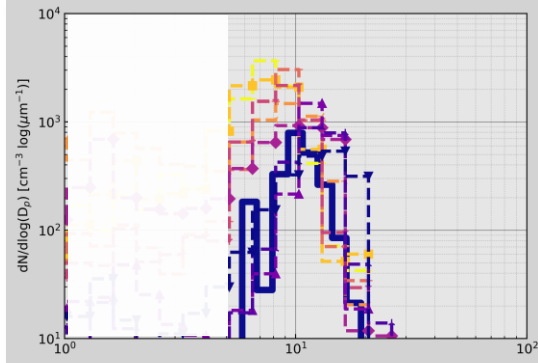
flare
[L⁻¹s⁻¹]

Liquid Distribution

Frozen Distribution

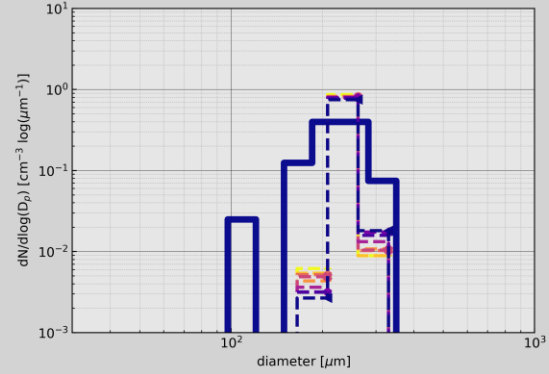
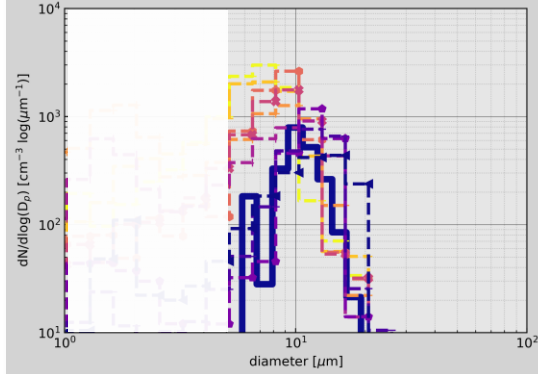
N_1^{CCN} N_2^{CCN}
[cm⁻³] [cm⁻³]

10¹¹



- M-[1035. 40.5]
- M-[1035. 20.5]
- M-[1035. 2.5]
- M-[600. 40.5]
- M-[600. 20.5]
- M-[600. 2.5]
- M-[200. 40.5]
- M-[200. 20.5]
- M-[200. 2.5]
- holimo

10¹⁶



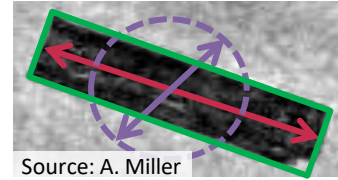
- M-[1035. 40.5]
- M-[1035. 20.5]
- M-[1035. 2.5]
- M-[600. 40.5]
- M-[600. 20.5]
- M-[600. 2.5]
- M-[200. 40.5]
- M-[200. 20.5]
- M-[200. 2.5]
- holimo

Varying background CCN:

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Size information from HOLIMO :

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concentration
[cm⁻³ log(μm⁻¹)]

diameter [μm]

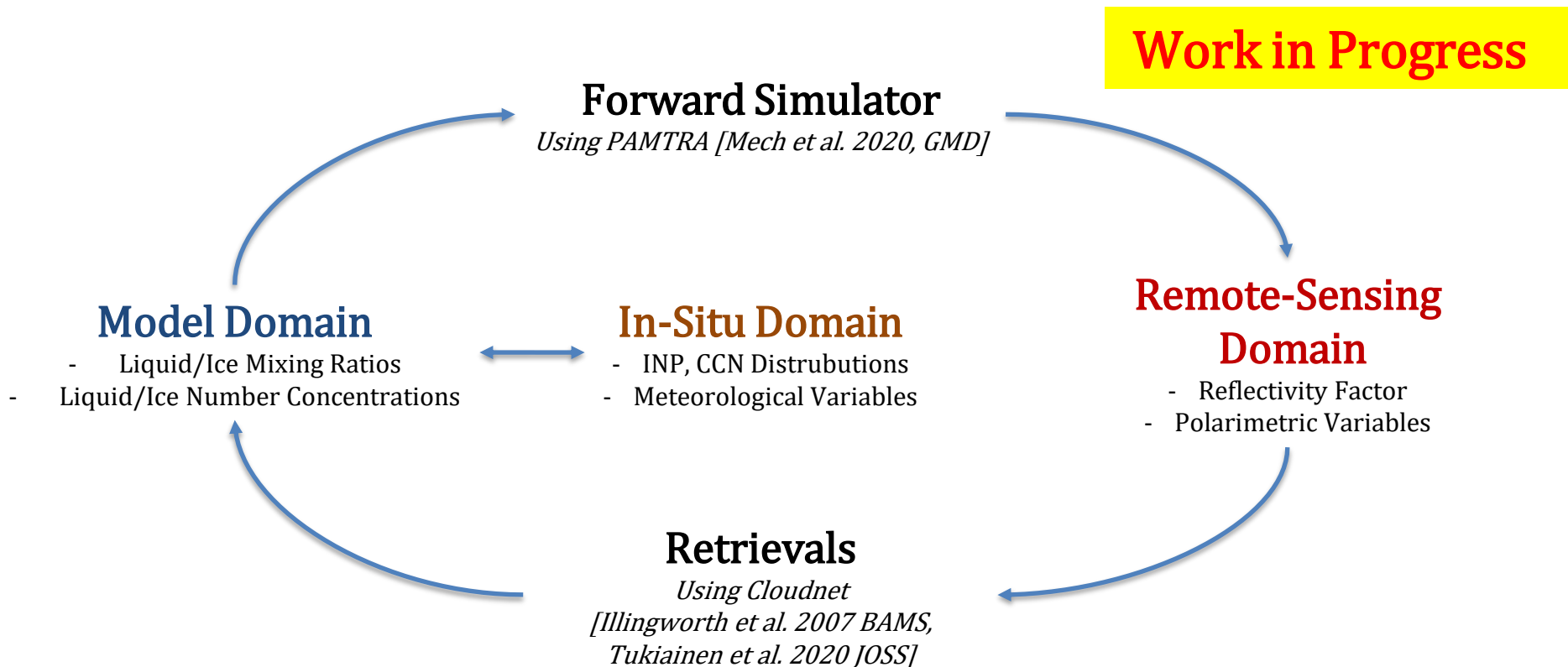
Summary

So far:

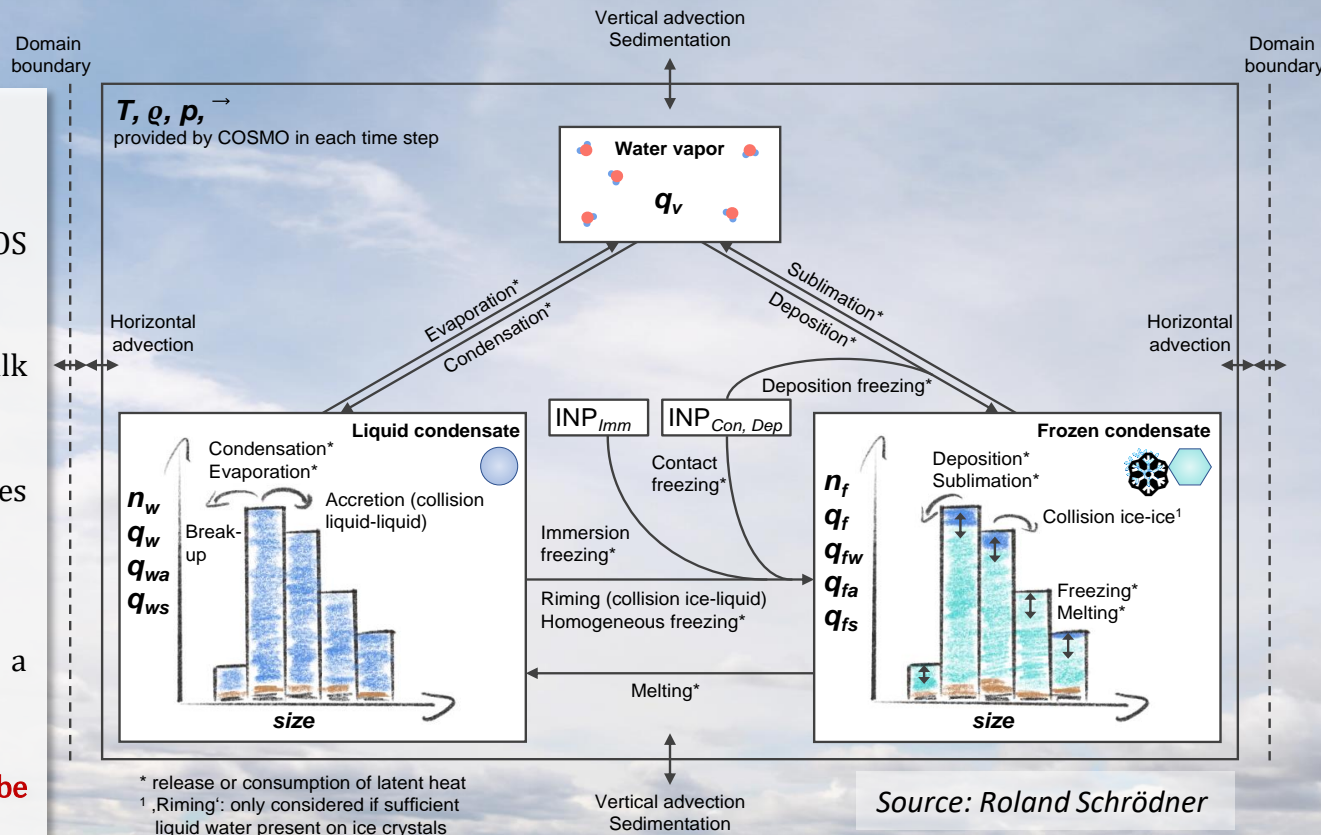
- ensemble simulations were carried out, varying in number concentration for initial CCN distribution and flare INP emission rates
- macrophysical properties in good agreement with observations (cloud base/top)
- microphysical properties in good agreement (number conc. & diameters)

Open Tasks:

- investigate ice growth process in specs (vary shape assumption)
- implement moving drone
- implement AgI parameterization [*Omanovic et al. 2024 (preprint), Marcolli et al. 2016, DeMott 1995*]
- run/analyze 100m - resolution model ensembles
- utilize Cloudnet-VOODOO retrieval → compare LWC/IWC & effective radii from retrievals to model
- Forward Operator PAMTRA [*Mech et al. 2020*]
- Lagrangian view, using cloud tracking tool tobac [*Heikenfeld et al. 2019*]
- (run ICON-SPECS)



- driving model: COSMO v4.21 [Schättler et al., 2013]
- SPECS developed at TROPOS [Simmel et al., 2002]
- SPECS replaces 2-moment bulk microphysics of COMSO
- liquid and frozen condensates distributions evolve freely
- ***NEW* flare:**
adding INP/CCN source to a specific grid cell
- **ice crystal shape assumed to be spherical for all hydrometeors**



COSMO-SPECS-Flare Setup

- COSMO-SPECS-Flare **adds** and **artificial CCN** and **INP source** to an individual grid cell
- Two switches control the background concentration of **CCN (varies)** and **INP (fixed)**
- Two switches control the artificial seeding, which adds **CCN (switched off)** and **INP (varies)**

400m horizontal resolution

dims	N cells	resolution	size
x (lon)	50	360 m	18 000 m
y (lat)	40	400 m	16 000 m
z (hgt)	100	9 m – 520 m	900 m – 21500 m

Parameter

Values

Background number concentration:

INP (fixed value) in $[L^{-1}s^{-1}]$:	:: N^{INP}	{500}
CCN (<i>varies, 2 modes</i>) in $[cm^{-3}]$: - $d_1^{liq} = 100nm$:: N_1^{CCN}		{1035, 600, 200}
- $d_2^{liq} = 350nm$:: N_2^{CCN}		{40.5, 20.5, 2.5}

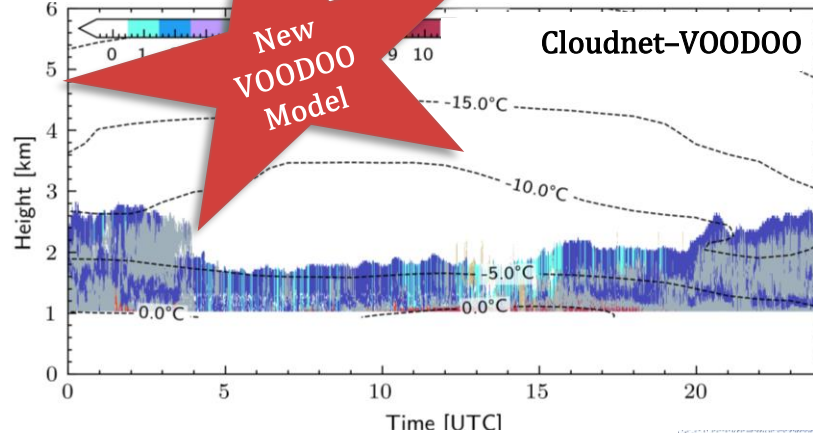
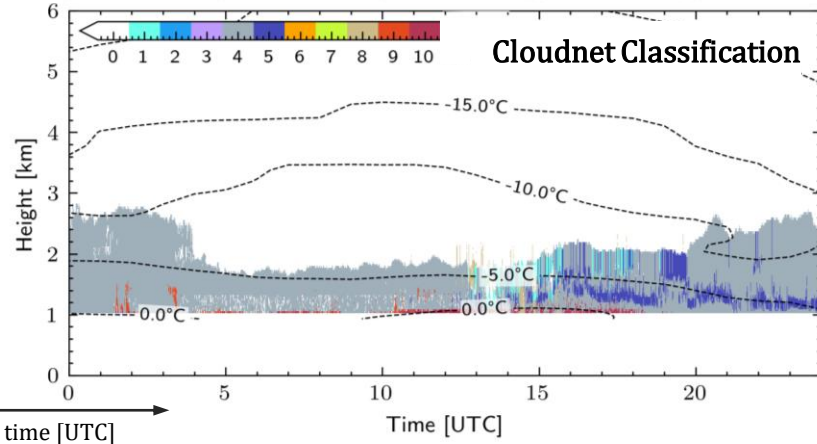
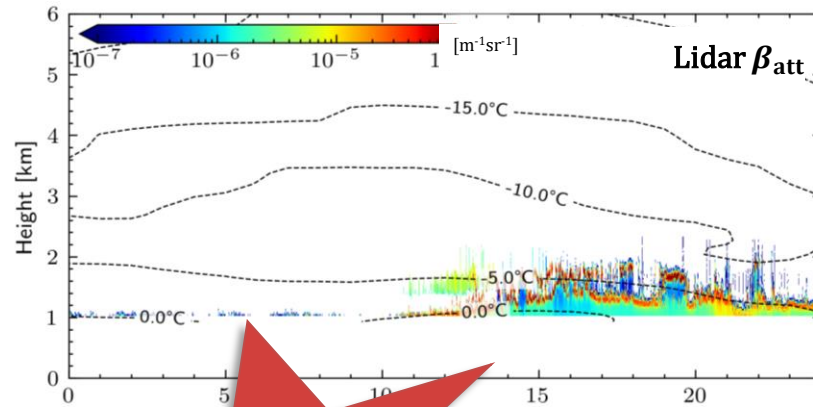
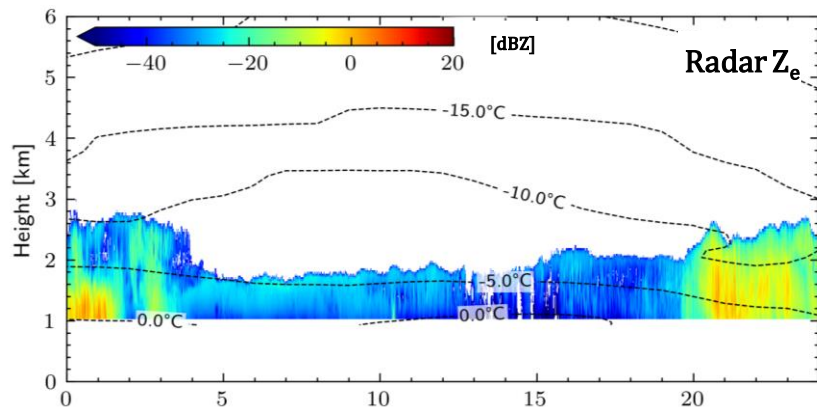
Artificial sources:

INP (varies) in $[L^{-1}s^{-1}]$:	- flare emission rate :: N_{flare}^{INP}	{None, 10^{10} , 10^{16} }
	- CCN modes ::	{None}

⇒ Number of model runs:

27

Issue with Low Level Liquid Clouds and Cloudnet



New
VOODOO
Model

liquid droplets

mixed phase

ice

TROPOS

Observations: LACROS

HATPRO G5
Microwave radiometer

Streamline Pro ("Shaun")
1.5- μ m Doppler lidar

PollyXT
Raman polarization lidar

MRR-Pro
24-GHz micro rain radar

Mira35 STSR
35-GHz Cloud radar

CE318-T
Solar lunar photometer

Parsivel
1D-Disdrometer

Holimo - HOLographic Imager
for Microscopic Objects

RPG94 FMCW-DP
94-GHz cloud radar

CHM-15kx
Ceilometer

LIMRAD94
scanning 94-GHz
cloud radar
(2023-2024)

VISSS
Video In Situ
Snowfall Sensor
(2023-2024)

2DVD - 2D
video
disdrometer



Source: Kevin Ohneiser

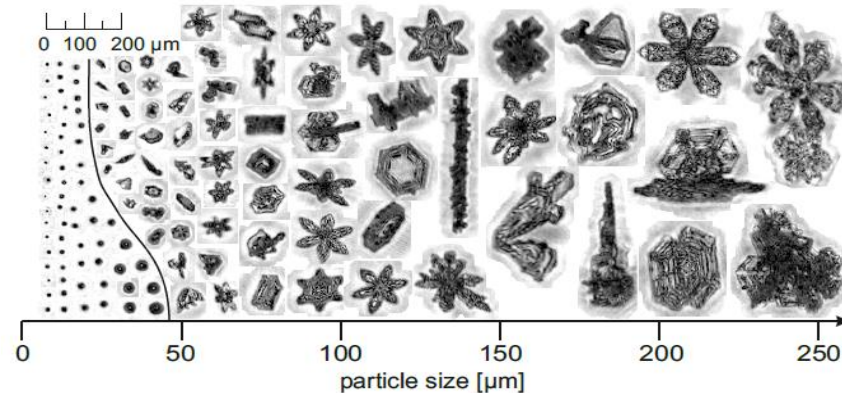
TROPOS

The holographic imager: HOLIMO



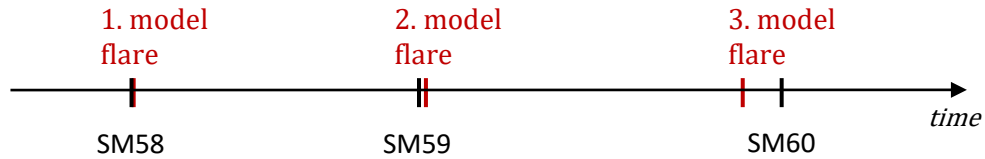
Capabilities:

- Cloud droplets $\geq 6 \mu\text{m}$
- ice crystal $\geq 35 \mu\text{m}$
- Max sampling volume:
 $22.5 \text{ cm}^3 * 40 \text{ Hz} = 0.9 \text{ l/s}$
- Cloud droplet and ice crystal
 - Number concentrations
 - Content
 - Size distributions

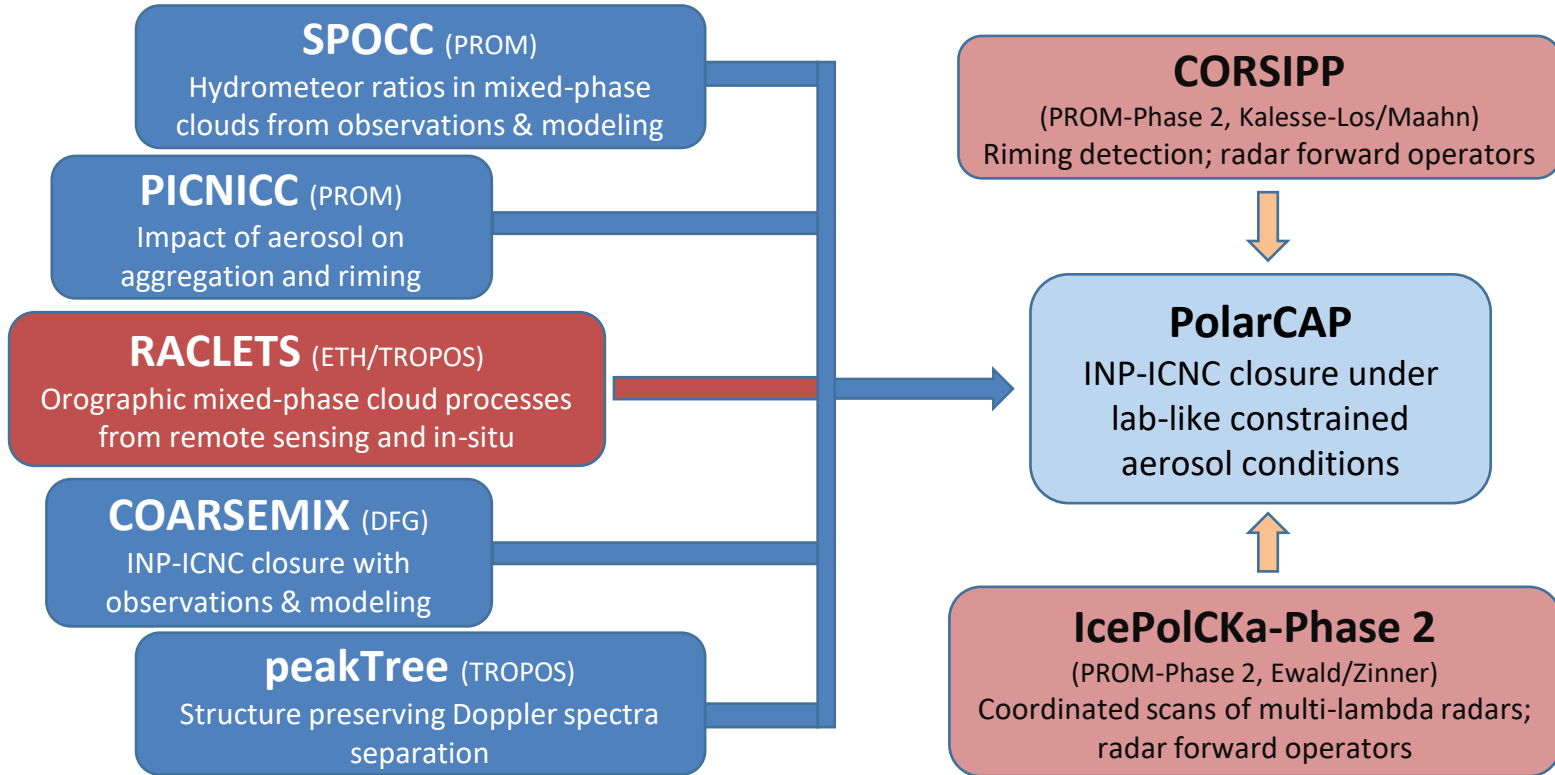


Source: Christopher Fuchs (ETH)

Seeding plume arriving at LACROS site VS model seeding:

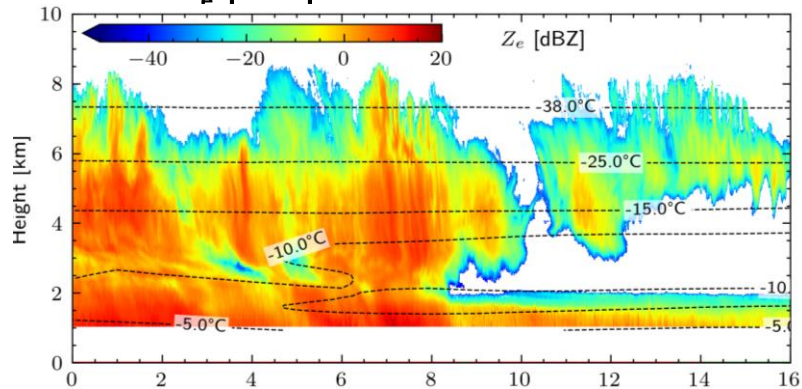


Supporting studies in the SPP-PROM network

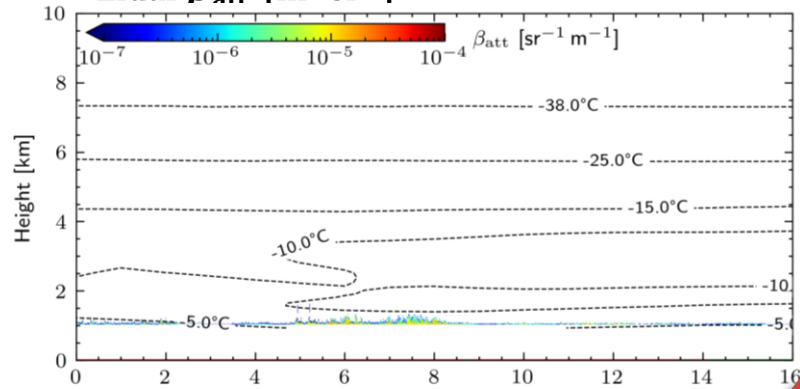


Issue with Low Level Liquid Clouds and Cloudnet

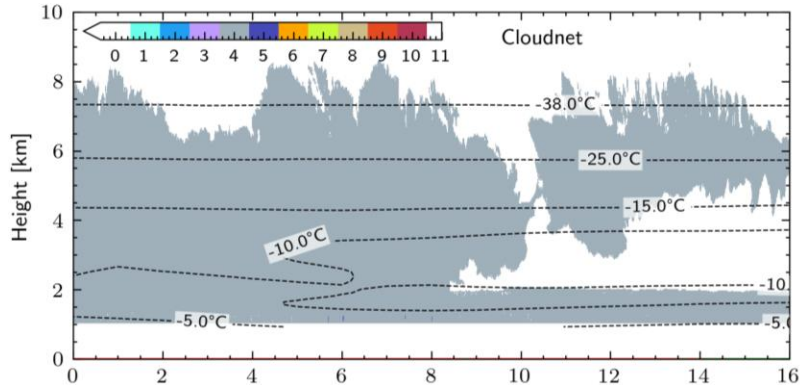
Radar Z_e [dBZ]



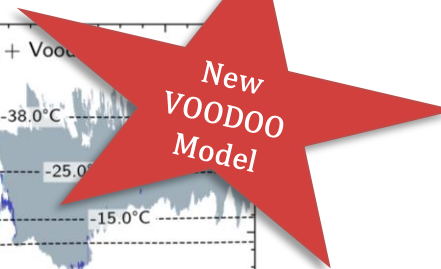
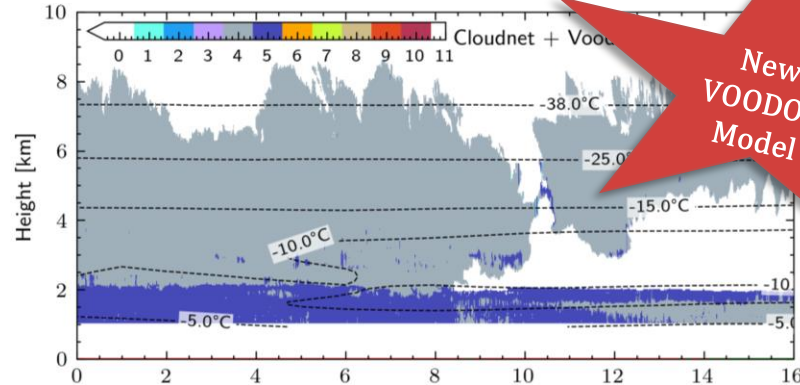
Lidar β_{att} [$m^{-1}sr^{-1}$]



Cloudnet Classification



Cloudnet-VOODOO

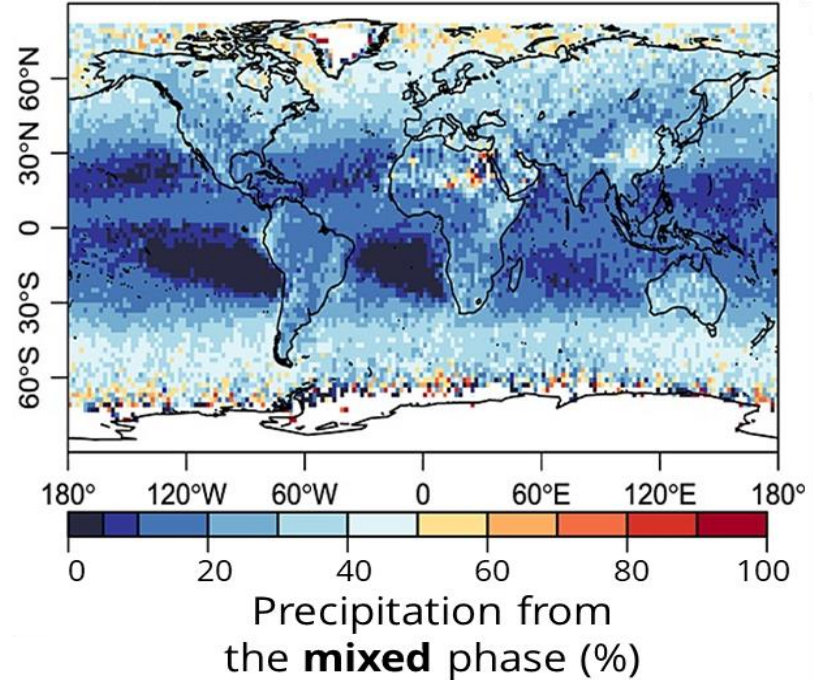
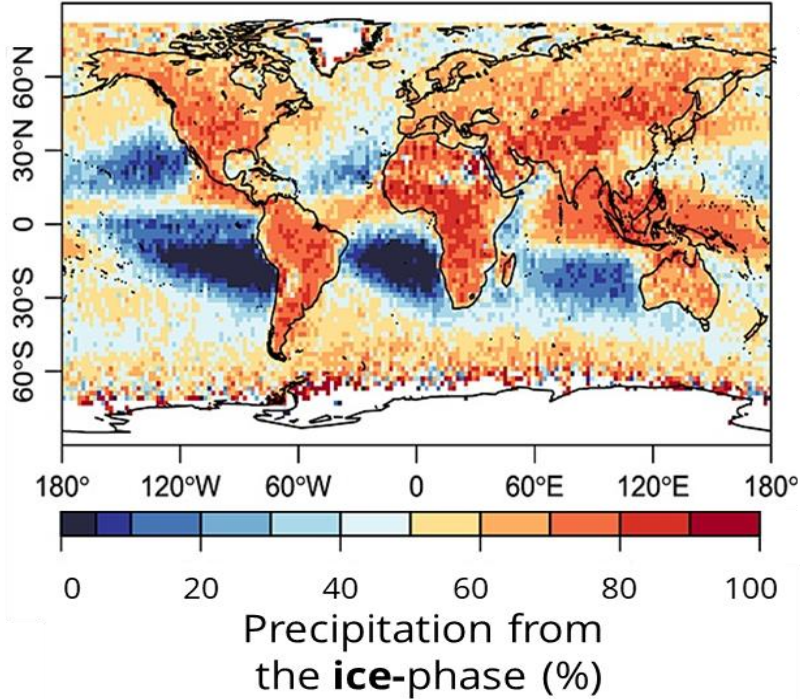


height [km]
time [UTC]

liquid droplets mixed phase ice



Importance of Ice/Mixed Phase Precipitation



[Mülmenstädt et al., GRL, 2015]

Supercooled stratus clouds as natural laboratory

Glaciogenic seeding



Low stratus clouds



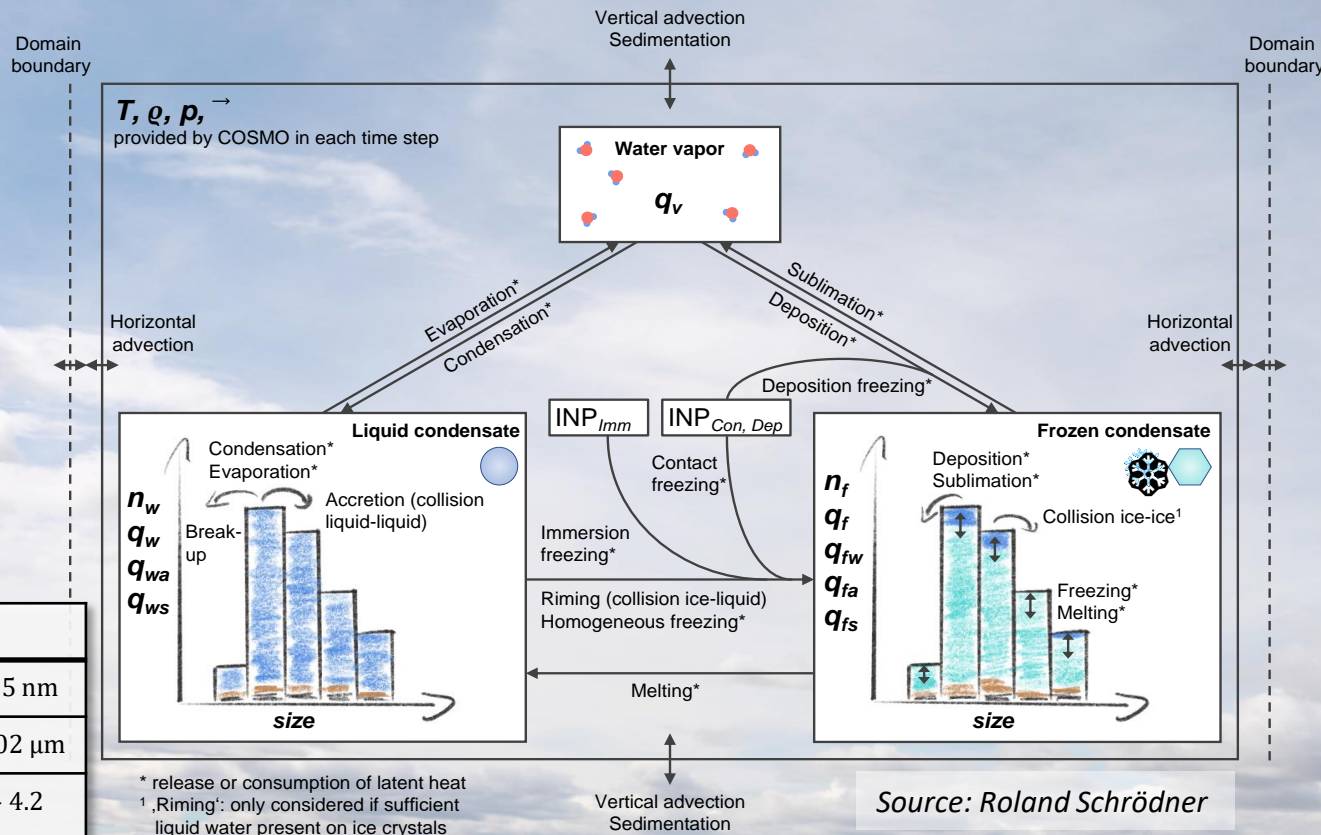
Seeding with a UAV



Source: jan.henneberger@env.ethz.ch

- driving model: COSMO v4.21 [Schättler et al., 2013]
- SPECS developed at TROPOS [Simmel et al., 2002]
- SPECS replaces 2-moment bulk microphysics of COMSO
- Liquid and frozen condensates distributions evolve freely

Number of bins = 66	bin	size
aerosol	1 - 30	1.0 nm - 1015 nm
droplets / ice crystals	31 - 50	1.015 μm - 102 μm
rain / snow / (precip.)	50 - 66	0.102 mm - 4.2 mm



Preliminary Results



COSMO-SPECS Model Domain: Eriswil

400m - Resolution

dims	N cells	resolution	size
x (lon)	50	360 m	18 000 m
y (lat)	40	400 m	16 000 m
z (hgt)	100	9 m – 520 m	900 m – 21500 m

Runtime 3 h simulation: 4.5 h on 1 node on Levante (128p)

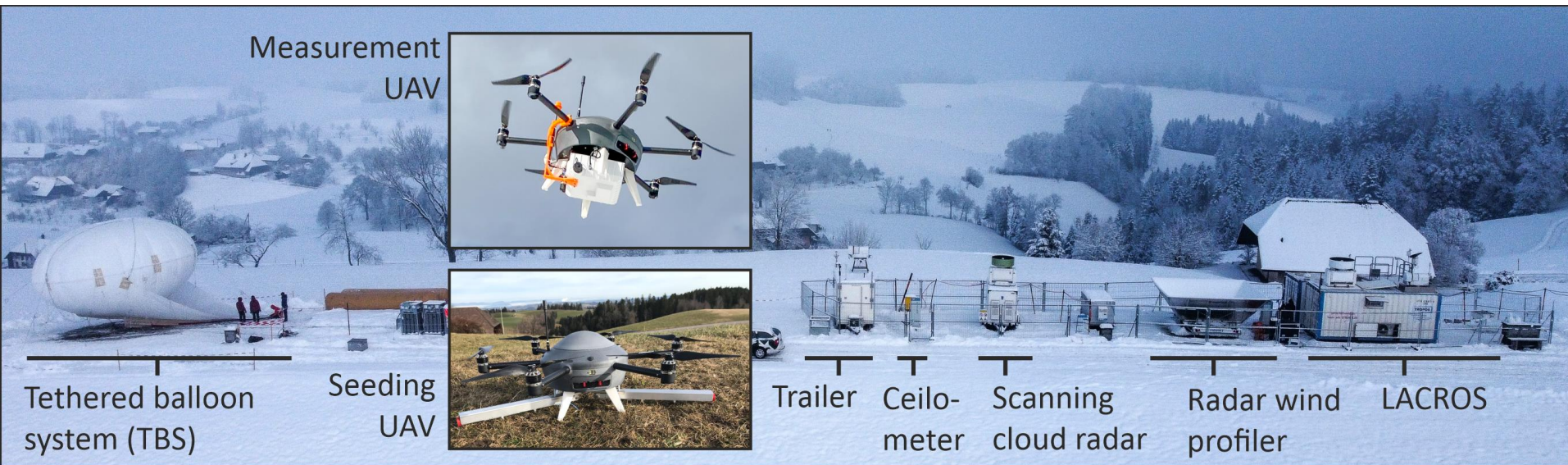
TARGET: 100m - Resolution

dim	N cells	resolution	size
x (lon)	200	90 m	18 000 m
y (lat)	160	100 m	16 000 m
z (hgt)	100	9 m – 520 m	900 m – 21500 m

Runtime 3 h simulation: 12 d on Gauss5 (176p)

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Observations: CLOUDLAB



[Henneberger et al., 2023, BAMS]



Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Eidgenössisches Departement des Innern EDI
Bundesamt für Meteorologie und Klimatologie MeteoSchweiz

MeteoSchweiz

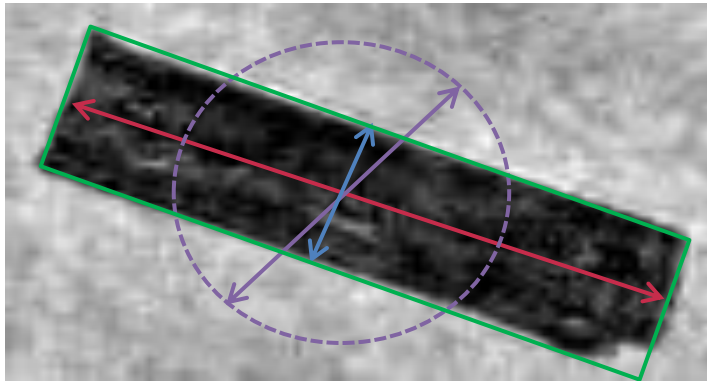
ETH zürich

TROPOS

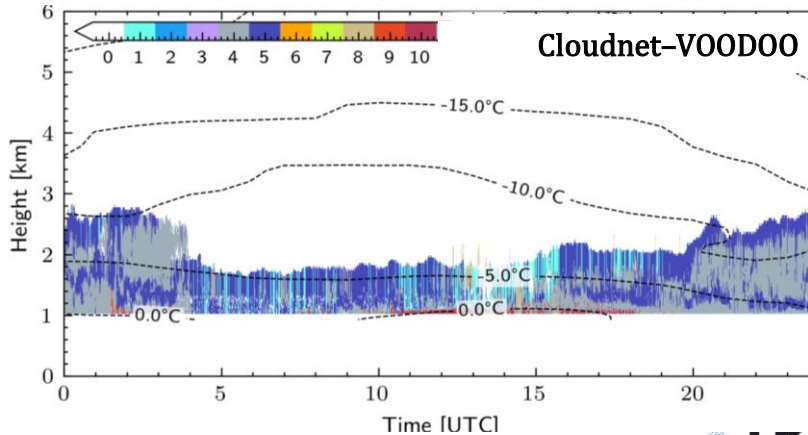
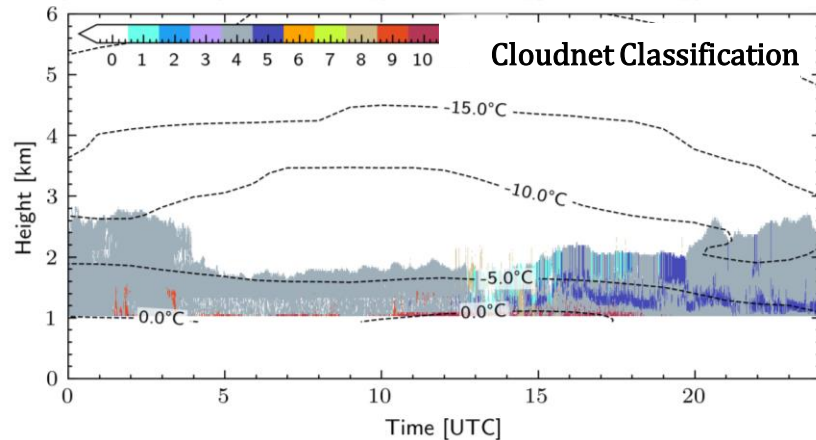
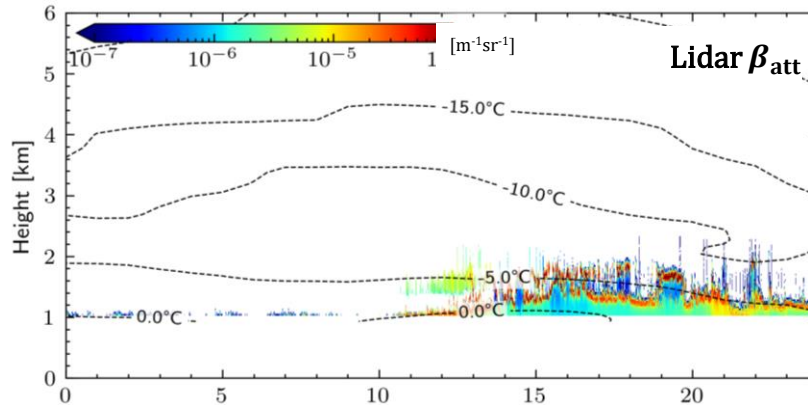
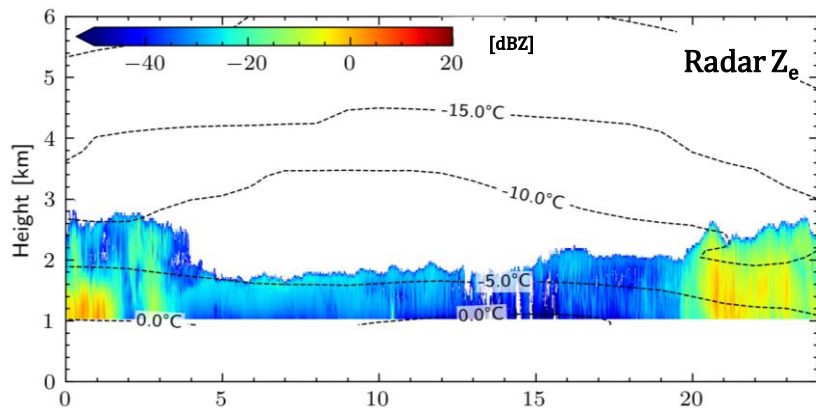
Ice crystal shape size

Size information from HOLIMO:

- Major axis length
- Minor axis length
- Equivalent size
- Area



Issue with Low Level Liquid Clouds and Cloudnet



Time [UTC]

Time [UTC]

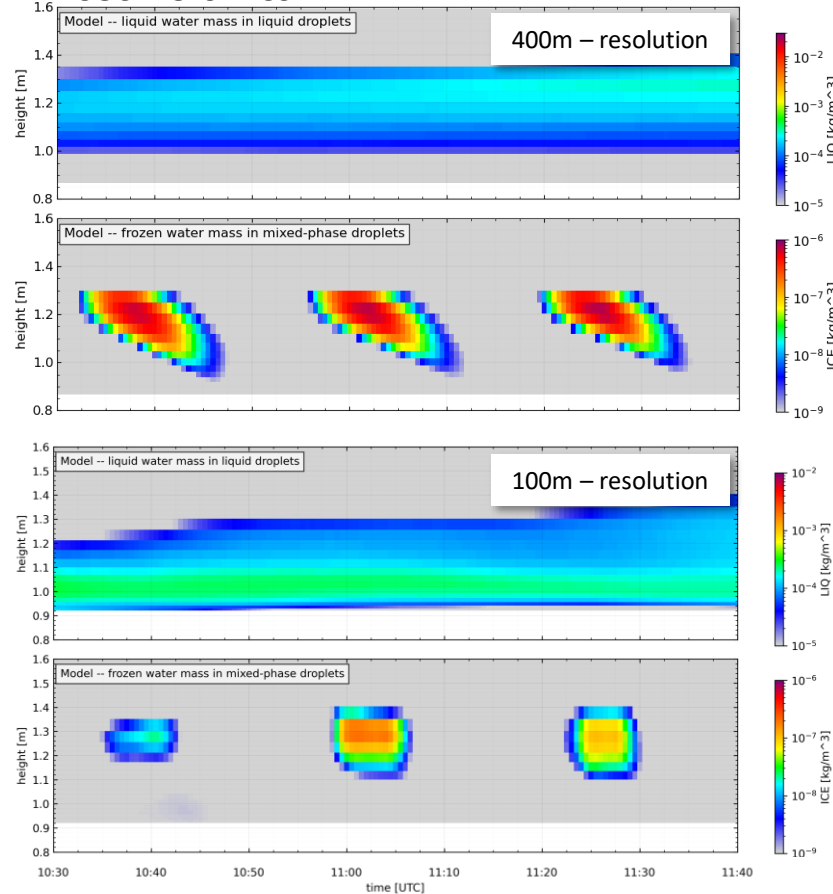
liquid droplets

mixed phase

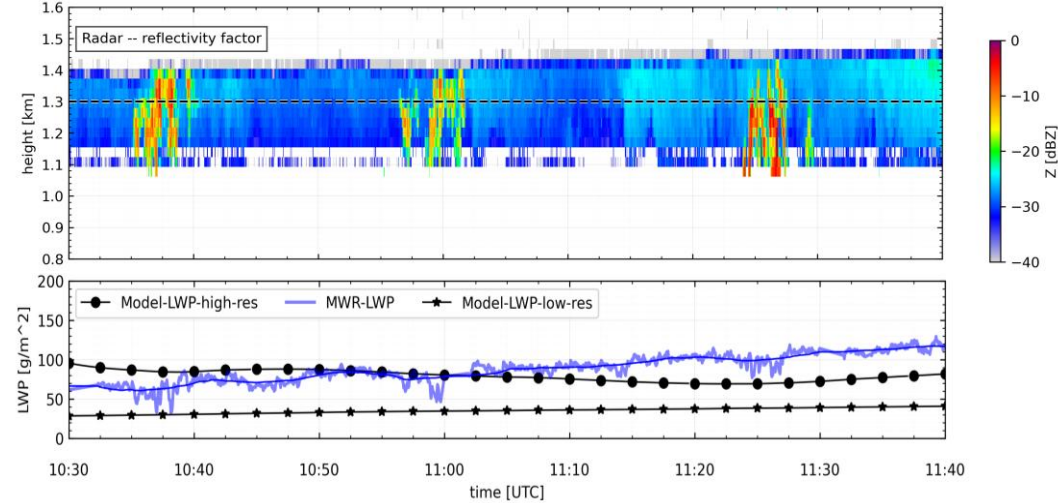
ice

Profiles at Rapier Platz: 25. January 2023

COSMO-SPECS

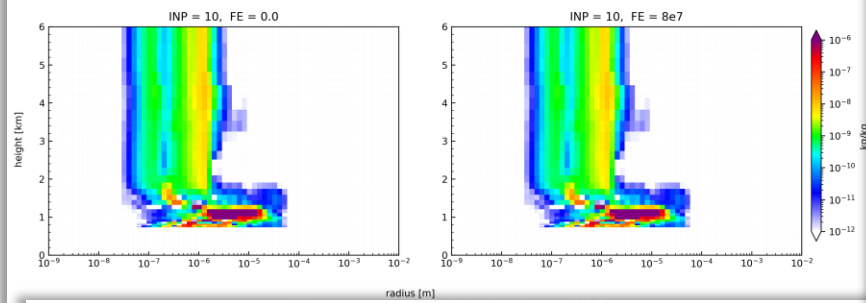


Radar – MWR – Observations

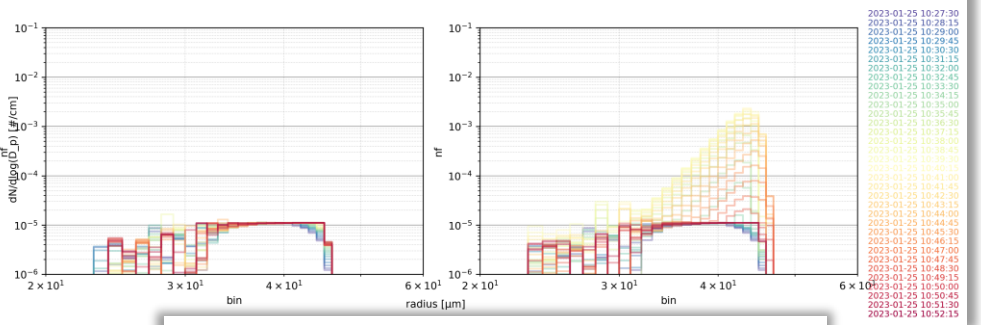


- Flare: low_res = $8 \cdot 10^{12} \text{ s}^{-1}$ (160s), high_res = $8 \cdot 10^{14} \text{ s}^{-1}$ (340s)
- Large spread in low_res frozen mass despite shorter flare burning time
- high_res cloud base 200m lower than radar observations
- MWR-LWP 10x (2x) higher compared to low (high) res. simulation

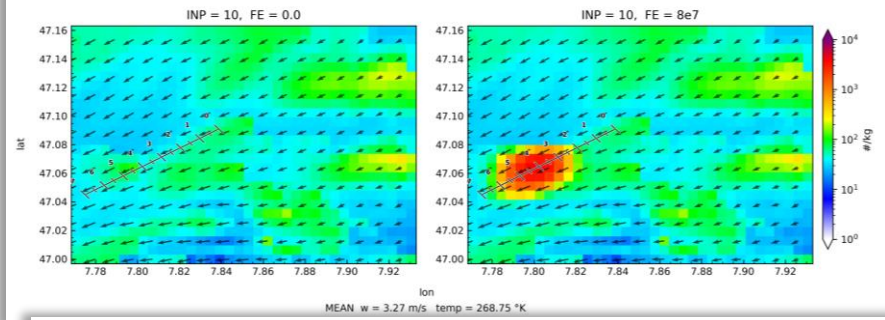
2023-01-25 09:03:30 - height: 0.743 - 1.258 [km]
sum of water mass in liquid droplets MR (nf)



Temporal Evolution of mixed-phase droplet number concentration
@47.064/7.798 and z = 1.258 [km]

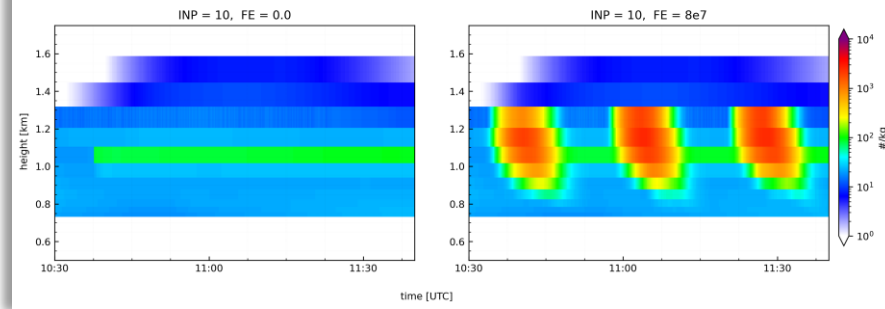


2023-01-25 11:27:00 - height: 0.743 - 1.258 [km]
sum of mixed-phase droplet number concentration (nf)



MEAN w = 3.27 m/s temp = 268.75 °K

lat/lon :: 47.0639/7.7981 dist = 2.518
Time Series of sum of mixed-phase droplet number concentration (nf)



2023-01-25 11:42:15 - height: 0.743 - 1.258 [km]
sum of mixed-phase droplet number concentration (nf)

